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Human Error and Organization Factors in Bridge Design and Construction

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Author(s): C. J. Turkstra - University of Waterloo
N. C. Lind - University of Waterloo

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Contact Person: Peter Smith, Director
(416) 235-4707

Abstract: This report describes a study of the formal and informal organizational structure of the bridge design and construction process in the Ministry of Transportation of Ontario (MTO). By means of personal interviews with a number of MTO engineering staff, an attempt was made to discern how the process operates and identify elements which might contribute to increased risk both to public safety and to the quality of completed bridges.

In the report, brief descriptions of the formal organizational structure are given, along with a description of communication links, information networks, responsibility assignments and internal checks on performance. A case study of a troubled bridge project is used to identify and categorize several specific problems related to communications and procedures within the MTO.

Since the study was very limited in scope and objectives, recommendations are not formulated. However, a number of suggestions concerning the organizational structure and design practices within the MTO are put forward.

Comments: The project was guided on behalf of MTO by a steering committee with P. Smith as chairman and D. Barnes, H. Grouni, A. McConnell, J. R. Wear, and A. Wittenberg as members.

Key Words: bridge design, bridge construction, organizational errors, human error, risk to public safety

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C. J. Turkstra

N. C. Lind

University of Waterloo

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For additional copies, contact:
The Editor, Technical Publications
Room 320, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 235-3480
Fax: (416) 235-4872

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1/ Introduction

1.1/ Objectives and Scope

Over the past decade, the importance of organizational arrangements, communications networks, lines of responsibility, and other human factors in the field of structural engineering has become widely recognized. This report describes a study of several aspects of the bridge design and construction process of the Ministry of Transportation of Ontario (MTO) that affect the safety, reliability, and durability of finished structures.

The study was motivated in part by the realization that state-of-the-art design codes and standards are not sufficient to assure the highest possible level of quality in construction. Factors not considered in conventional design dominate the risk of unsatisfactory performance.

This concern is heightened by plans for significant increases in budgets for bridge construction in Ontario. Such increases will place additional strain on the MTO organization with attendant increases in risk and threats to overall quality.

Another major concern arises from the fact that many senior engineers and managers joined the Ministry during a major expansion in the 1950's. Many experienced people are expected to retire over the next few years. Having worked together for many years, these senior people enjoy an ease of communication that will be difficult to maintain or re-establish during a period of rapid staff turnover.

As new junior engineers are recruited and rapid promotions take place, there will be a critical need to transfer experience over a short period of time. Carefully designed training programs to accelerate the maturing process must be developed. It is essential that the quality assurance program of the Ministry be clearly documented.

Finally, given the impending volume of activity and staff turnover, the possibility of simplifying the design and construction process has been raised. This study will suggest ways in which this might be approached.

This preliminary study reviewed the organization of the bridge design and construction process of the MTO with special reference to communications, information networks and authority structures. The bridge design and construction processes within the Ministry are embedded within a complex network of interacting units. The first level of division is

between Head Office in Downsview and five major Regions, each with its responsible hierarchy and operating units. Attention is limited to Head Office, Southwest Region, and Central Region. Although the information obtained was rather limited, an attempt will be made to relate observations to management and communication principles as a framework in which potential changes can be discussed.

1.2/ Methodology

The approach adopted in this study was to interview a limited number of Ministry personnel in Southwest and Central Regions and in Head Office. The objectives of these interviews were to:

Identify the participants and stages in bridge planning, design and construction.

Identify relevant communication links, paperwork flows, responsibility structures, approval processes, filing arrangements, quality assurance measures, and problem resolution paths.

Identify selected MTO directives, forms and manuals.

Obtain data on actual bridge cases, to identify the nature of problems and verify the relationship between actual and theoretical practices.

A list of the people contacted is attached as Appendix A.

2/ General Background

2.1/ Structural Safety

Through the development of structural design standards, substantial improvements in safety and economy of bridge structures have been achieved in this century. Basic documents such as **The Ontario Highway Bridge Design Code** (MTO 1983) have evolved, along with reliability theory and risk analysis, which provide a logical structure through which structural safety is controlled.

Unfortunately, reliability theory is inherently limited, partly because no theory can make up for the lack of data that is characteristic of real bridge design and construction. Another limitation is that reliability theory can only control risk associated with uncertainty in

physical quantities – in its present form, the theory assumes that a structure is designed, built and maintained correctly.

A number of studies and reports have shown that as much as 80% of structural risk is associated with human behavior and organizational factors (Matousek 1977). Over the last decade, some theoretical groundwork has been laid, notably by Blockley (1980), Kupfer and Rackwitz (1980), Lind (1983) and Melchers and Stewart (1985). A summary was presented by Turkstra (1988).

This work is primarily of two kinds: fundamental empirical studies and phenomenological models of human error (Nowak 1986). Apart from the pioneering effort of Pugsley (1968) and an unpublished study by Fox (1982), there have been few attempts to integrate this knowledge into the practical management of structures.

The evolution of engineering practice in recent years has increased the importance of organizational arrangements, communications networks, lines of responsibility and other human factors for several reasons. These include: changes in the number and variety of participants (such as construction managers) in the construction process; societal changes that affect the training and motivation of people; and the growth of repair and renovation projects which involve a great deal of uncertainty. Recognizing this situation, the American Society of Civil Engineers has published a multi-disciplinary manual on the control of quality in construction projects (ASCE 1988).

In other branches of engineering, such as the nuclear and chemical industry, where risk affects a large portion of the population, major efforts have been made to develop a methodology for **Institutional Quality Assurance** and development of a **Safety Culture** within organizations. These will be discussed in a subsequent section.

2.2/ Communication Theory

One of the vital components of control of human factors is the development of effective communications within organizations (U.S. Congress, 1984). Related research is primarily in the fields of industrial psychology and sociology. A review of communications theory in a civil engineering context was presented by Santamarina and Chameau (1989). Lockley (1989) attempted to apply principles of communications theory to several structural failures.

While many useful concepts have been developed, and empirical studies have been completed to establish many of the reasons for faulty communications, the field is

characterized by a highly specialized vocabulary which is not familiar to most engineers (Appendix B). What is clear is that effective communication requires adjustments to attitudes and shared meaning – not just a transfer of information. It requires common interest and continual feedback to ensure that the intent and content of a message is correctly received. Failure to understand these principles has contributed to many major civil engineering accidents, and to the poor performance of many designs (Santamarina and Turkstra, 1989).

From an engineering point of view, existing communication theory has one major limitation – it does not consider the effects of professional ethics or requirements to take personal responsibility for actions through professional stamps and signatures. Associated with these requirements are the positive and negative effects of "esprit de corps", as well as a shared commitment to the public good. One of the major conclusions of an international summit meeting on quality assurance in structural engineering , sponsored at Rigi by IABSE, was that the best and only reliable approach to the control of human behavior is self control developed through education and tradition (IABSE, 1983).

The role of professionalism and self-discipline is of major importance in this study.

2.3/ Institutional Quality Assurance

Over the past decade, "Quality Assurance" has proven successful in reducing the incidence of faults in manufacturing processes. In response to public concerns over safety, the Advisory Committee on Nuclear Safety of the Atomic Energy Control Board attempted to apply similar principles to entire organizations and set out several principles of "Institutional Quality Assurance" in a recent report (ACNS 1990).

Requirements for organizations were listed as follows (in alphabetical order):

Accountability. Institutions, as well as individuals, must be accountable for their actions having a potential effect on safety and must be subject to audit.

Authorization. Institutions must ensure that no action may be taken without due authorization.

Independence. Auditing and regulation must be performed by individuals, groups or institutions organizationally independent of those responsible for implementation.

Integrity. Any information used by an institution and having a potential effect on safety must be of high integrity.

Measurement. An institution's management systems must include processes to measure their performance.

Responsibility. Responsibilities (and demarcations between responsibilities) within the institution must be clearly assigned.

Traceability. All chains of responsibility and of reasoning within an institution must be clearly traceable.

Visibility. The total process must be as open as possible to public inspection.

These criteria will be used as a basis for evaluating the MTO design and construction process in this report.

2.4/ Classification of Errors

In an analysis of historical situations in which human factors played a major role, a classification of error types and organizational causes must be developed. One of the first such systems for a review of insurance records of structural failures was developed by Matousek (1980). For the present study, a broader methodology which includes factors internal to an organization is required.

A more general approach to case study analysis was developed by Pate-Cornell and Bea (1989). Based on an examination of problems associated with the NASA space shuttle disaster, as well as experience in offshore technology, "organizational" problems were broken down into two basic types.

Gross Errors are defined as those which are uncontroversial and arise from a decision maker's avoidable lack of knowledge or understanding. The decision would have been different if he had had better information. Sources of such errors include communication problems, limitations of human abilities due to, for example, inadequate training, and an inappropriate transfer of decision criteria from one situation to another.

A second class of problems are termed **Errors of Judgment.** These involve situations where information is open to interpretation and differences between individuals are inevitable. Differences may arise because scientific data is limited or because value judgments are required in a decision. In related cases, facts are inherently uncertain and there is no "right" answer.

Elements of both type of problem can be identified in the MTO cases studied.

3/ Related Organizational Structure of the Ministry

3.1/ Terminology

To clarify the following discussion, several terms must be defined in a way that does not strictly conform to Ministry usage. Within the Ministry, **planning** is used to describe two processes – (1) the development of background data, preliminary studies, cost analysis, budgeting, environmental studies etc. that precede a decision to build a bridge and (2) the first stage of the detailed development process where the geometry, and type of bridge are established. In Ministry usage, **design** means the choice of the details of a bridge structure.

To clarify the situation, the term **preliminary design** will be used to denote the final stage of the bridge planning process, and the term **detailed design** will be used to describe the second stage of the process. **Planning** will be used in its more conventional sense to describe the pre-engineering process leading up to the allocation of a budget for a bridge project. In many cases, pre-engineering planning cannot be done without a certain amount of preliminary design to provide feasibility and cost data for the budgeting process.

Another source of semantic confusion is the overlap of some words in the designation of organizational units. For example, the Structural Office is in Head Office while the Structural Sections are in Regional Offices. For those within the organization, this does not seem to pose a problem, but given the interaction between the groups, some confusion is inevitable for an external person. As will be discussed subsequently, the semantic confusion between structural groups is matched by some confusion over roles and responsibilities. To avoid confusion, offices are occasionally labeled (SWR), (CR) and (HO) to denote the Southwest Region, Central Region and Head Office respectively.

3.2/ Head Office Organization

Under the **Assistant Deputy Minister for Engineering and Construction**, Head Office provides several vital components of design and construction as well as support, auditing, and control functions. A simplified organizational diagram is shown in Figure 1.

Most of the line departments that are directly involved in design and construction report to the **Executive Director of the Highway Engineering Division**. The **Manager** of the **Structural**

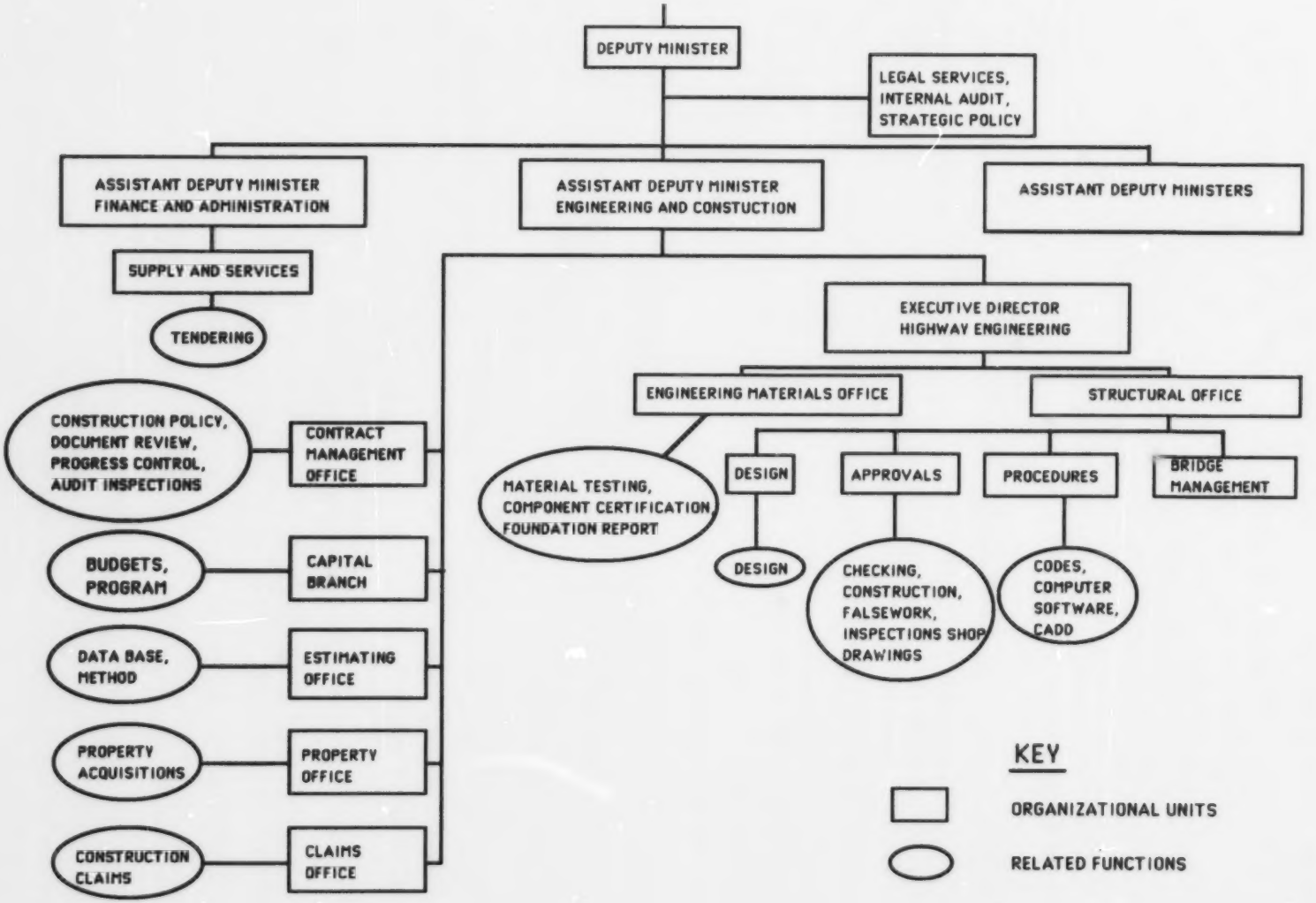

Figure 1/ Head office organization (partial)

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Office manages four major groups headed by senior engineers - **Design, Approvals, Procedures and Bridge Management.** The Design and Approvals groups are directly involved in program delivery, while the Procedures group provides technical support such as standards and software. The Bridge Management group is primarily involved in post-construction activities.

The **Head** of the **Approvals Section** supervises several important subgroups. For new bridge design and construction, the most important of these are the **Review Engineering** and **Construction Engineering**

Within the **Engineering Materials Office**, two vital program functions are maintained – a geotechnical design and testing group which provides **Foundation Reports** and an approvals group for new materials and construction components.

Also located at Head Office and reporting directly to the Assistant Deputy Minister for Engineering and Construction are the **Contract Management Office**, the **Estimating Office**, the **Property Office** and the **Claims Office**. These offices are primarily involved with construction contracts. **The Contract Preparation and Control Section** within the Contract Management Office controls advertisements for bidding on all capital contracts within the Ministry.

The contract tendering process is controlled by the **Supply and Services Branch** under the **Assistant Deputy Minister for Finance and Administration.**

3.3/ Regional Organization

Within each region, relevant operational authority is vested in two managers - the **Manager of Engineering and Right Of Way** and the **Manager of the Construction Office** under the **Regional Director** (Figure 2).

The Manager of Engineering directs a number of sections, of which two are central to bridge work – the **Structural Section** which is responsible for bridge development and the **Planning and Design Section** which is responsible for highway design (alignment, subgrade, pavement), provides surveying information and coordinates liaison both within the Ministry and with outside agencies such as utility companies and environmental control groups.

A key element in the design process is the **Project Manager**. For projects involving highway, as well as bridge design, the project manager is selected from within a specially qualified group within the Regional **Planning and Design Section**. In such cases, for bridge design, the

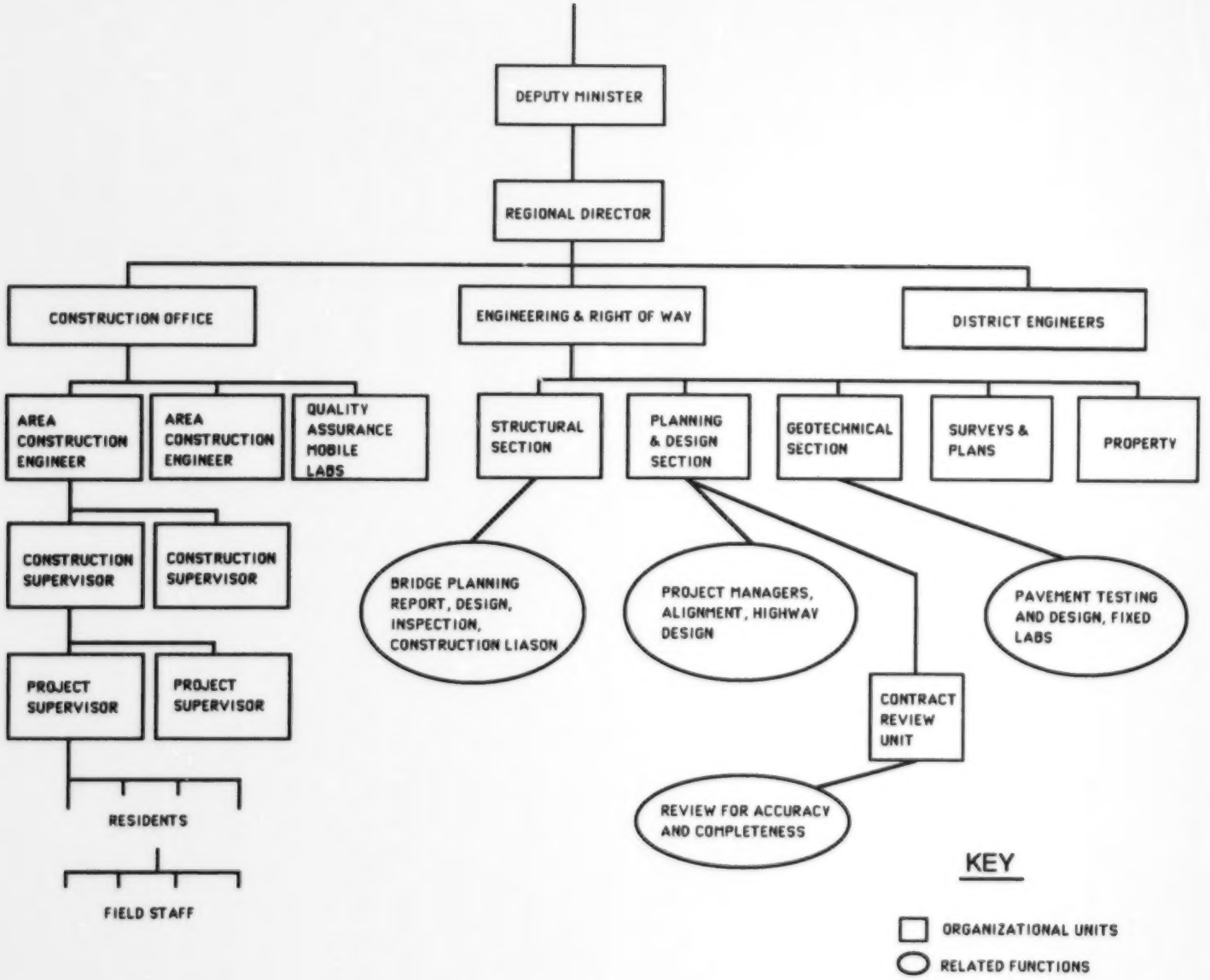

Figure 2/ Regional organization (partial)

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Project Manager functions within a matrix organization – working with both the Structural Section and the Planning and Design Section. For projects which are primarily bridge design, the project manager may be selected from the Regional Structural Section.

Within the Regional Structural Section, several types of work have been identified, e.g. structural planning, structural design, and inspection. Generally, engineering staff work in all areas as required.

The Regional **Contract Review Unit** plays a vital role in the final design stages before construction begins.

Regional **Construction Offices** are organized on a hierarchical basis – below the **Manager of Construction** are **Area Construction Engineers** followed by **Construction Supervisors, Project Supervisors** and resident project staff. Regional **Quality Assurance** groups are also maintained as support staff for testing and quality control.

4/ The Formal Design and Construction Process

The design and construction process under consideration begins when the **Regional Manager of Engineering and Right of Way** receives formal notice that a project has been included in design and/or construction budgets for a specific program year. Prior to this event, Regional and Head Office staff may have been involved in route planning, feasibility and preliminary cost assessments.

In a limited number of unusual cases such as major bridges or new arterial highways, special groups may be formed that cut across the Regional/Head Office organizations. For bridge design, such cases generally involve relatively new or sophisticated technology and ad hoc organizations are formed. For this study, such special cases are not considered.

For simplicity, the following description is based on practices in Southwest Region where, because of relative size and scope of work (and probably also because of distance from Head Office) lines of responsibility and authority are quite clear. The situation in Central Region (which is in principle quite similar but more complex) is discussed in a following section dealing with differences in practice.

4.1/ Design

The first step in the process is the appointment of a **Project Manager** from the **Planning and Design Section** who has overall responsibility for coordination between bridge and highway work, scheduling during the pre-construction stages, document preparation, arranging progress and approval meetings and ensuring necessary signatures (Figure 3). Within the **Structural Section,** an individual is assigned responsibility for each bridge and to work with the overall Project Manager.

A schedule following a standardized sequence of operations is developed to cover the design process and related approvals. Bi-weekly scheduling meetings are set up to monitor progress. At this time a site plan showing natural features, utility information and the location of the proposed bridge is discussed at formal and/or informal familiarization meetings between individuals and groups in the Ministry.

Development of engineering drawings, specifications and contract documents prior to the tendering process involves a number of formal stages. While these stages progress, many other activities are taking place. For example, final alignments are being developed, the roadway is being designed, property is acquired and environmental concerns are addressed. These other activities may totally dominate the time schedule within which bridge engineering and construction can take place.

4.1.1/ The Bridge Planning Report - Structural Section

The project leader in the **Structural Section** begins by collecting all relevant information and establishing contact with related outside agencies (e.g. conservation authorities, electricity and telephone utilities, railways and waterway control officials) generally through the **Project Manager** who has overall responsibility for the progress of the project.

A formal request is made for a **Foundation Report** from the **Engineering Materials Office (HO)** which may do it internally or commission a consultant. Information on foundation locations, and loading data is provided and the Foundation Report recommends foundation type and soil bearing capacity.

Geometric calculations are performed in cooperation with the highway design team in the Planning and Design Section.

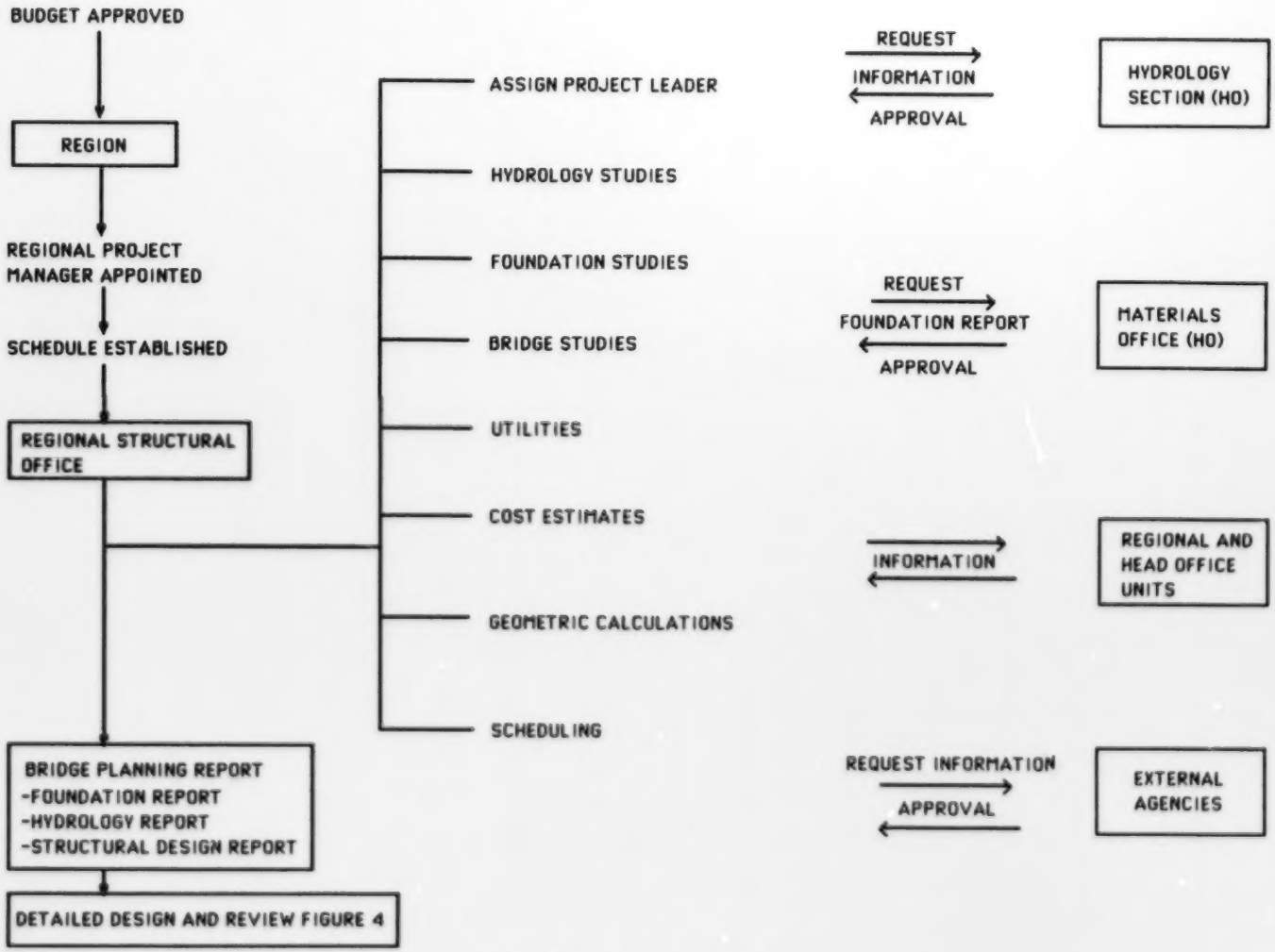

Figure 3/ Preliminary design process

If hydrological features are involved, a **Hydrology Report** is prepared suggesting specific embankment control measures and clearances, for example. This may be done in the Structural Section or by a consultant with data from Head Office and related authorities.

Essential bridge features such as spans, bridge type and materials, and cross-sections are established (generally after informal consultation with the **Structural Office (HO)** in a **Structural Design Report**) This report details the rationale for the technical decisions.

Cost estimates are developed along with rough estimates of the time needed for construction. Geometric calculations are performed if necessary.

A **Bridge Planning Report** consisting of the Structural Design Report, the Foundation Report and the Hydrology Report (if necessary) is prepared. This report gives the general layout, location of existing utilities, the bridge alignment, vertical profiles, and proposed cross-sections and details of traffic staging, for example.

4.1.2/ Detailed Design

If it is decided that a project will go forward for detailed design, The **Structural Office (HO)** is consulted as to who will undertake detailed design. Structures are categorized as "Simple", "Intermediate" or "Complex," with the Regional **Structural Section** responsible for complete design of simple structures. Intermediate structures are divided between the Regions and Head Office on the basis of available resources and interest. Complex designs are left to the **Structural Office (HO)** or consultants.

In general, if the Structural Office (HO) does not have the resources to design a bridge, the Regions commission a consultant, after conversations with the Manager of the Structural Office (HO). Regional authorities retain administrative control (budget and schedule) of consultants, while the Structural Office (HO) provides technical guidance for all intermediate and complex structures (Figure 4).

In Southwest Region about 15% of designs are performed by Head Office and about 75% by consultants. In Central Region, very few designs are completed by Regional staff.

If a consultant is to be given a design project, the selection is made under tightly controlled conditions by a **Regional Consultant Selection Committee** as explained in the following discussion of formal control mechanisms. An official **First Meeting** is held with the consultant to develop terms of reference, schedules and fees. The consultant is provided with

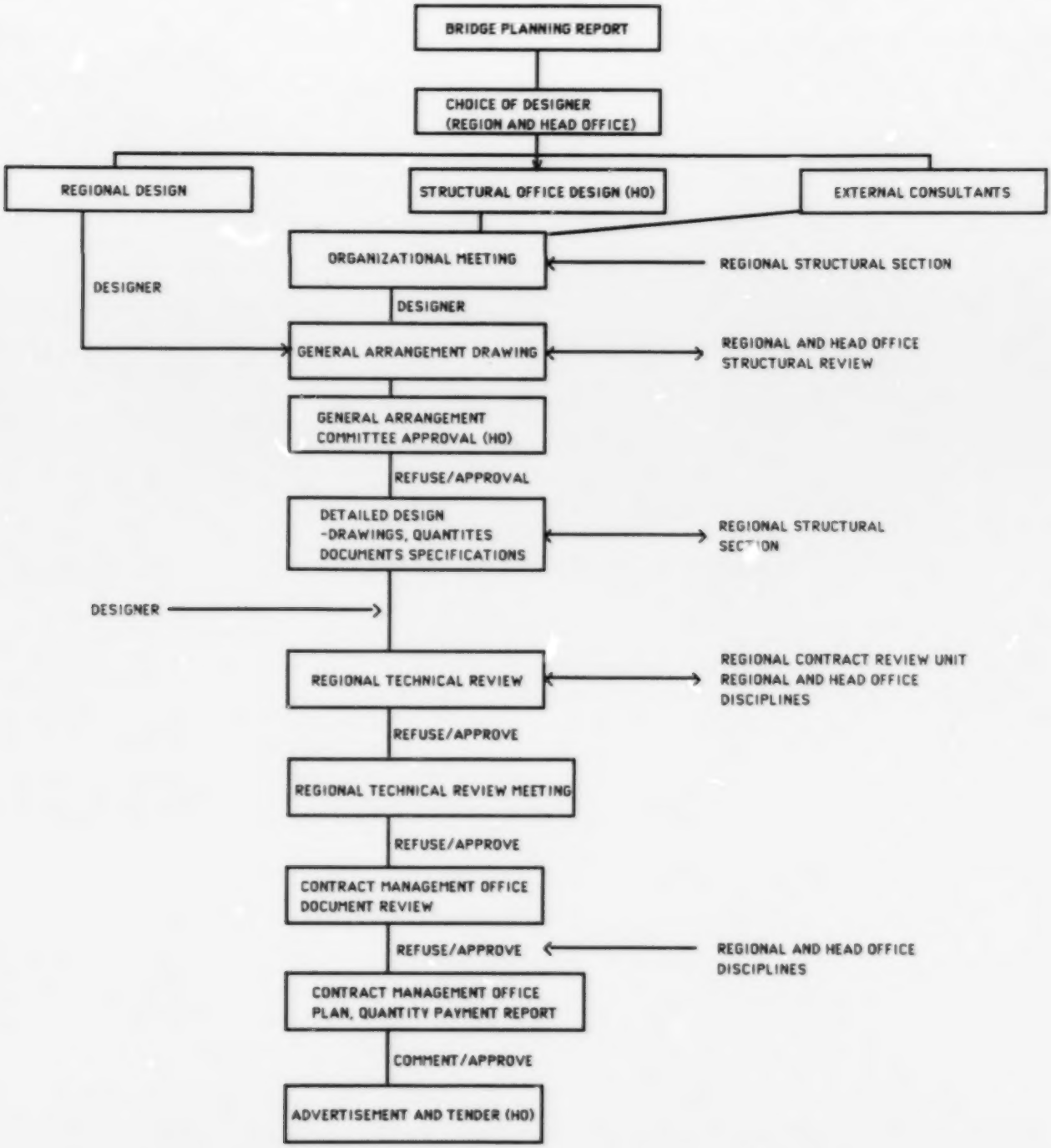

Figure 4/ Final design and review

the Bridge Planning Report and information on Ministry design standards, drawing and specification standards, and other Ministry resources and procedures.

If a design is done internally within a Region, both technical and administrative responsibilities are vested in the Region. If design is performed by consultants, administrative control is retained by the Regions while technical guidance is provided by Head Office.

The first stage is preparation of a proposal in the form of a **General Arrangement Drawing**, which is officially submitted to the Ministry-wide **General Arrangements Committee** in Head Office. This Committee must report and approve of the proposal in writing with comments before design work can continue.

The designer then completes the design calculations, drawings, specifications, reinforcing schedules and contract quantities using Ministry codes and standards including many standard drawings, as well as approved materials and construction techniques. A number of liaison meetings between designers and others within the Ministry are normally required during evolution of the design.

The **Project Manager** in the Planning and Design Section combines the bridge contract package, including lists of quantities with a similar highway package and initiates the formal technical review process.

4.1.3/ Technical Review

During the first stage of review, the contract package is submitted to the Regional **Contract Review Unit** which reviews legal aspects of the documents. At the same time, the package is submitted to related Head Office disciplines which have several weeks to respond – if they wish.

The package is then submitted to a list of Regional offices and disciplines including the **Construction Office**. The formal **Regional Technical Review Meeting** is scheduled with a standard agenda including comments from, for example, the **Property Section**, the **Estimating Office** and from those in related disciplines such as environmental officers. Materials and services to be provided by the Ministry, special provisions, traffic arrangements, stockpiles, and sources of materials are discussed.

If consultants are involved, they are required to attend the Technical Review Meeting.

4.1.4/ Final Review

The revised contract package is then submitted to the **Contract Management Office (HO)** for Document Review with comments returned for consideration by the Region. This technical review deals primarily with quantities, standards and specifications.

At this time, the Regional **Construction Office** is involved in formulating a response to the Head Office review of the contract package.

When an agreement has been reached, the contract package is submitted for formal **Regional Executive Review** where it is signed by the **Regional Director** and the **Manager of Engineering and Right of Way**.

Finally, the contract package is resubmitted to the **Contract Management Office (HO)** which prepares a report on the quantity payment arrangements and to the **Contract Preparation and Control Section (HO)** for tendering, assuming that the project budget contains funds for construction and that Ministry priorities have not changed.

4.2/ Construction

Prior to tendering, the **Regional Construction Office** is invited to comment on proposed designs at several stages. The Office receives the Bridge Planning Report and may be consulted in the preliminary design stage, but the first serious involvement is a review of the General Arrangement Drawing early in the detailed design stage.

When the first draft of a complete design package is available, the Construction Office completes a constructability review, comments on unusual factors or potential problems and suggests simplifications or alternatives. Discussions involve staging, scheduling, and traffic considerations, for example. Since a representative attends the formal Technical Review Meeting, the Construction Office is familiar with most of the details of each project before it is tendered. The Construction Office does not see Ministry cost estimates.

When a construction contract has been let, a **Construction Project Supervisor** from the Regional staff is appointed and a First meeting with the Contractor is scheduled. At this meeting, the so-called **Pass Over Ceremony**, the Contractor is required to name his project manager, and arrangements are gone over in great detail including lines of communications. The contractor is required to present a detailed schedule with, for example, staging constraints. Alternatively, he may accept the Ministry schedule provided, at his own risk.

Before construction begins, Ministry arrangements for quality assurance and field control staffing are established. In general there will be a number of Regional technicians for each highway project to perform aggregate, concrete, asphalt, and soils testing. Except for several special cases, testing is performed in a Ministry Regional Laboratory or field laboratories. As well, there are site inspection staff for routine checking of reinforcing, dimensions, and elevations, for example.

In special cases, the **Materials Office (HO)** is directly involved in construction through certification of proposed materials and assemblages such as bearings and expansion joints. Foundation engineers may also be involved in the resolution of construction problems.

Strength tests of concrete and steel are performed by private independent laboratories hired by the Contractor. In such cases Ministry responsibility is limited to a general inspection of field sampling and the approval of sampling techniques and laboratories.

In bridge construction, the **Approvals Section (HO)** of the Structural Office retains responsibility for several vital construction functions including the approval of all bridge falsework, bearings and expansion joints, steel shop fabrication, installation of steel work including weld inspection, and approval of prestressing arrangements and inspection. These are detailed in Directive B-147 (MTO, 1982).

If temporary structures are required, design is carried out by the contractor or his consultants and approved by the **Approvals Section** of the Structural Office (HO).

Problems experienced during construction are referred to the Regional Structural Section which communicates with Head office staff or project consultants as necessary.

At the completion of the project, a detailed Construction Report is completed by the Construction Supervisor. This will include "as built" drawings, photographs, a detailed evaluation of any problem encountered and recommendations for future consideration if appropriate.

5/ Organizational Constraints

Within the Ministry, there are many regulations and practices that directly effect communications, authority, and responsibility. These constraints provide checks and balances on the performance of individuals and departments.

5.1/ The Fundamental Directive

The most fundamental regulation is the overall policy statement **REGIONS ARE RESPONSIBLE FOR PROGRAM DELIVERY.** This decentralizing directive limits Head Office to planning, financial control, general supervision, support and auditing roles. Regions are responsible for bridge design and construction, with the Head Office providing standards and other forms of technical support.

In Directive B-147 (MTO, 1982), the nature of the relationship between the Regions and the Structural Office is spelled out in considerable detail. In view of the specialized nature of bridge design and practical limits on the size and sophistication of bridge design staff in the Regions, the role of the Structural Office in technical aspects of program delivery is established, but the overall administrative responsibility of the Regions is retained. The intention of the directive seems to be that the Structural Office in Head Office act as a consultant to the Regions in bridge program delivery.

5.2/ Project Managers - Scheduling

The role of Project Managers from the Regional Planning and Design Sections is vital to program delivery. With respect to bridge design, the Managers are responsible for ensuring that schedules are honored, all necessary approvals, notices and checks are completed and that official steps such as the Regional Technical Review Meeting are complete.

With respect to control of scheduling, Regional engineering offices, regular scheduling meetings are programmed and, in the case of Central Region, a specialized scheduling officer is available.

Within the Regions, overall responsibility for filing up to the point at which contracts are sent for tender rests with the Project Manager.

5.3/ Checklists, Stamps and Signatures

To assign professional responsibility, a number of stamps and signatures are mandated. In the preliminary design process, the "Foundation Report" must be signed and stamped by two

Ministry engineers or consultants. The "Hydrology Report" must be signed by the engineer responsible. The "Bridge Planning Report" is signed and stamped by the engineer responsible and the Head of the Regional Structural Section. Relevant external utilities and regulatory agencies are identified and contacted for approvals.

In the initial stages of detailed design, the General Arrangement Drawing must be signed and stamped by the designer and a checker. It must also be approved by the General Arrangements Committee (HO) with representatives from the Structural Office and Regional Structural Sections.

At the end of detailed design, drawings must be stamped and signed by either the Ministry engineer responsible for internal designs, or the consulting firm for external designs.

A separate professional engineers' stamp is required to certify that a design has been checked. If a design is done by a consultant, the independent check is the responsibility of the consultant. If a design is done internally in the Region or at Head Office, checking is performed by the Approvals Section (HO) of the Structural Office (HO).

Before submission for tender, a variety of Ministry departments must give approval. Finally, the **Regional Director** and the **Regional Manager of Engineering and Right of Way** must sign off on the contract package.

After regional approval, documents are reviewed by Head Office staff to assure conformity with Ministry practices, specifications and standards. However, in case of dispute, the Regions have final authority.

Before construction, drawings for shop work, major falsework, and temporary structures must be stamped and signed on behalf of the contractor by a professional engineer. They are also checked, stamped "Permission To Construct" and signed in the Approvals Section of the Structural Office. New materials, components and procedures are tested and certified in the Materials Office at Head Office.

During construction, detailed records of inspection and test results are mandated. Before every concrete pour, an inspection must be completed and "Permission to Pour" signed off by inspection staff. Site inspection is carried out and recorded by Head Office personnel for vital stages of major or innovative construction.

During construction, pier locations, geometry, and elevations are checked and certified by an external land surveyor.

When problems arise during construction which cannot be resolved informally, a "Field Instruction Notice" is issued. If problems remain, a "Contractor's Infraction Report" is filed with a committee at Head Office.

Head Office audits field supervision staff to ensure that Ministry procedures are followed, diaries and detailed inspection records are maintained as required, and that required inspection are performed.

The final construction report must be signed by four people in the Regional Construction Office.

5.4/ Selection of Consultants

The process of selecting consultants for planning, design, or technical support is closely controlled through Ministry Directive B-235 (MTO, 1985). When an office in a Region determines that a consultant is required and a budget is available, a Consultant Selection Committee is set up in the Region. This committee includes the Manager of Engineering and Right of Way, the relevant Section Head, one other Regional Manager, and a financial representative. A list of approved consultants is maintained with a historical record of assignments and current activity for each consultant. A list of 3 candidates in order of preference is established based on an equitable distribution of work called the "Roster-Rotation System."

This recommendation is submitted to the Consultants Assignment Committee (HO) consisting of the Assistant Deputy Minister for Engineering and Construction, the Executive Director of the Highway Engineering Division, and a chairperson. This submission is for approval only.

The list of consultants is open to anyone who can demonstrate related competence and experience. The list is segregated into specialties and, for highly specialized activities or very large assignments, few consultants may be available.

The performance of each consultant is reviewed after each assignment and a standard evaluation form must be signed by the Project Manager and his superior. If performance is less than satisfactory, a hierarchy of penalties comes into effect varying from warnings, to a

reduction of assignments until confidence has been restored, to complete removal from the list. All such penalties mus be approved by the Assistant Deputy Minister.

5.5/ Codes and Standards

Designs are completed using the Ontario Highway Bridge Design Code which is widely recognized as one of the most sophisticated codes in the world. Design drawings follow standard formats and extensive computerized files of standard details and material specifications are made available. State-of-the-art computer programs are provided for use by both internal and external design engineers.

Standard lists for the contents of the design package have been established and are checked off.

5.6/ Records and Checklists

During the review process, detailed checklists are used to ensure that all necessary steps have been completed. Lists of tasks to be completed and offices to be circulated for comment are standardized and the agenda for the final Technical Review Meeting has a prescribed comprehensive form.

Filing requirements are not completely laid down, but some policies exist. During the design and review process, the master file is kept by the Project Manager in the Regional Planning and Design Section. For bridges, files related to design and approvals are kept in the appropriate sections of the Structural Office (HO) and consolidated into a permanent file in that Office.

At the end of each project, a formal summary report is prepared.

6/ The Process in Practice

Inevitably, in any large organization, there are many variations from formal organizational structures to written procedures. In an environment as complex and dynamic as that of the Ministry, formal directives, manuals, and procedures are at best a summary of what is desirable at a particular point in time.

The dangers of an overly rigid organization are especially critical for a professional organization where many decisions require judgment and negotiated agreements between individuals and organizations. As the nuclear energy program in the United States has clearly demonstrated, overregulation can cripple the construction process. The willingness of individuals to use their own judgment and their competence to do so are essential if the organization is to accomplish its objectives.

In the following notes, a number of deviations from the formal Ministry organizational models are noted – not necessarily as criticisms, but simply as indications of how the organization actually works.

6.1/ Regional Differences

As might be expected, in an organization responsible for a great variety of projects over a large geographic area, significant differences exist between the activities and practices in the various regions. While the differences are in degree only, they have a profound effect on the design and construction process.

In the Southwest Region, for example, typical bridge projects are not as sophisticated technically as those in Central Region. Head Office is physically remote so the policy of Regional responsibility for program delivery can be applied with some clarity. Regional officials are properly protective of their responsibilities and authority.

In Central region on the other hand, projects tend to be more sophisticated with complex interchanges and multilane roadways through densely populated areas. Many interacting government bodies are involved, as are many external authorities. Pressure groups are politically sophisticated and well funded. Property acquisition, for example, is relatively much more controversial and political pressures to accelerate program delivery are intense.

Central region is located in the same building as related Head Office departments.

The combination of these factors has had a number of effects on basic organization in the Central region.

> Central Region has introduced more specialty departments such as a scheduling office and a process control office. The addition of such functional groups complicates the authority structure and makes communications more difficult.

The Structural Section in Central Region does relatively little design, leaving the work to the Structural Office (HO) or consultants. Even though they are notionally "responsible for program delivery," supervision of bridge consultants may be left to Head Office.

Due to work and time pressures, Central Region is introducing consultants into the preliminary design process. External consultants are becoming involved in the preparation of "Bridge Planning Reports" which is one of the prime functions of Regional Structural Sections.

The workload in Central Region and the pressures to complete projects are so great t hat the official sequence of design and technical review may not be completed. Thus, for example, the Foundation Report may not be completed before the Bridge Planning Report is circulated and detailed design has been initiated. Mandated engineering stamps to certify that design has been checked may not be on drawings. Projects may go out for tender before all reviews and signature are complete.

Construction problems may be referred directly to the Structural Office (HO) without passing through the control of the Regional Section.

The primary effect of these realities is a blurring of the responsibilities of Central Region and Head Office structural groups. Structural Section in Central Region is becoming a project management group rather than a hands-on engineering group. Even within this limited role, the Structural Section does not exercise full responsibility for program delivery.

6.2/ Communications

The Design and Construction organization within the Ministry is characterized by experienced, professional engineers in senior positions. Given their many years of association, shared educational backgrounds and common experience, it is not surprising that communication between departments in the Regions and Head Office are generally easy. Informal communications (shortcuts) are routine.

One major result of this situation is that the process of approvals can be pushed along through telephone calls and peer pressure.

During the interviews in Southwest Region, a relatively high level of satisfaction with the process was found. There is a crisp understanding of who is responsible for what and paths of

information flow are defined, documented, and respected. Major grievances were limited to delays in the "Technical Review" process.

In Central Region, the situation was rather different. The Structural Section and the Planning and Design Section did not seem to be in close communication. Among the people in Planning and Design there seemed to be a general sense that structural people are a different species and do things their own way.

Although it cannot be documented and nothing was said explicitly, the general sense of confidence in the process and in related departments seems to be much less in Central Region than in Southwest Region. For example, when asked directly if it is possible that projects could go to tender without a complete Bridge Planning Report or certification of a separate design check by a professional engineer, all of those asked hedged their responses.

One rather unexpected observation in the Structural Section of Central Region concerns the filing system. In fact, there did not seem to be a clear policy for filing and no formal process was laid out. Responses included comments such as "everyone knows where to go for information."

In an examination of the rather chaotic files for two projects in the Structural Section, no copy of a letter of direction or terms of reference for the external consultants were found.

The Planning and Design Section of Central Region has overall responsibility for documentation during the highway and bridge design process. Filing procedures are well defined and, judging from an examination of two projects, are maintained by project managers. Material from the Structural Section was not complete. Structural people were said to "do their own thing."

It should be noted that the Structural Office (HO) maintains a formal filing group with filing clerks and procedures.

In Southwest Region, the responsibility of the Structural Section to resolve problems during construction was clearly recognized. Contractors must designate a responsible person for each project and are routed to the Structural Section through the Ministry Construction Supervisor for field problems associated with bridges.

In Central Region, this function of the Structural Section has become confused. Based on a very limited sample, it seems that the normal path for construction problem resolution is

through the Approvals Section of the Structural Office (HO). This routing makes sense since many elements of field inspection for complex bridges are the responsibility of the Approvals Section who are thus well known to field personnel. As well, complex bridges are designed in Head Office or by consultants under their technical supervision.

6.3/ Scheduling

In both Regions, formal, computerized scheduling control for the design and construction process is exercised in the Planning and Design Sections. There were some complaints that others failed to honor time commitments.

The primary focus of such complaints was directed towards delays "caused" by Head Office in the review process. Many of the objections raised in such reviews were thought to be trivial. On the other hand, people involved in the procedural review complained of carelessness in the preparation of contract documents by design staff and especially consultants.

It is not clear to what extent such complaints are "buck passing" and the result of a natural and inevitable conflict between doers and checkers. It is also not surprising that Ministry personnel would have some antagonism to outside consultants and people from other parts of the Ministry – within limits, such rivalries contribute to the development of "esprit de corps" and provide useful checks and balances.

What seems clear is that the focus of delays and uncertainties in scheduling during the pre-construction process are associated with the technical review process.

6.4/ Uncertainties in Budgeting

One of the facts of life within the Ministry is significant uncertainties in the timing of construction projects. Capital budget allocations are not stable with repeated cycles of feast and famine.

During periods of lean budgets, Ministry staff are available to complete designs for future projects which are then stockpiled. When construction budgets are made available, these designs are reactivated and, after a cursory review, are sent for tendering.

Given the complexity of the highway design process with reviews by many external agencies and property acquisition problems that can stretch over many years, the environment of a highway can change dramatically between design and construction. New utilities can be in place, whole new towns may develop and practices that are acceptable to one generation may

become wholly unacceptable to another. New agencies may come to life that did not even exist at the time of design. An obvious example is the change in environmental standards for noise and pollution.

Within the Ministry, significant personnel changes may occur over time with the result, for example that the engineer responsible for the "Bridge Planning Report" may be in another Region or have retired. If nothing else, such changes can make communications very difficult and damage the reputation of the Ministry in public forums.

In periods of budget injections, the Ministry finds itself with an inadequate supply of experienced personnel and consultants who are not fully familiar with Ministry requirements and procedures. When the demand for consultants increases, the competition for qualified engineers increases and the incentives for Ministry personnel to leave for private practice increase. At a time when the Ministry most needs experienced staff, the working conditions for such staff become less attractive.

The implications of this problem are beyond the scope of this study, but it is clear that the problem is of major importance. Stabilization of engineering work load and personnel can only contribute to improved quality in construction.

6.5/ Professional Development

Throughout the Ministry, there is a long standing practice of moving engineers through various stages of design and construction in the Regions and Head Office. Thus, for example, the Head of a Regional Structural Section may have worked in the Head Office design group, been responsible for field supervision in a construction office or held responsible positions checking designs or supervising testing.

One of the impressive characteristics of the Ministry is the depth of commitment to the principle that engineers are professionals with high ethical standards. Formal policies require individual signatures on many documents and those who are not able to handle such responsibility are moved out of front line positions.

As a result of the clear structure of authority, there are significant incentives for junior engineers to excel at their work and to assume personal responsibility for their actions. High morale and loyalty to the mission of the Ministry were clearly evidenced by most people interviewed during this study

One item of contention relates to the liability of professional engineers for their decisions. The Ministry has taken the position that its engineers must answer to the courts for their negligence – a position taken by a number of European governments with their staff engineers. It is felt by some that such a policy might discourage engineers from making decisions. Others feel that good engineers welcome responsibility – those who are not prepared to take it should not hold senior positions.

Another contentious item concerns the need for engineering qualifications in some positions. The question of whether there should be a "resident engineer" on major construction sites has been debated for some time.

6.6/ Useful Jargon

During interviews in the Southwest Region, it was observed that two common themes have been developed that provide a common focus on objectives and a unifying criteria for quality.

Throughout the design process, the phrase "Complete the Box" is used and serves to maintain a constant focus on the objective of preparing a set of contract drawings, specifications and documents. Such organizational tricks are very useful in establishing a common purpose and a clear end product of the process.

A useful aid to quality assurance in the Southwest Region is the use of the questions "Is it Biddable" and "Is it Buildable?" in the technical review process. This theme succinctly summarizes the point of technical review and unifies design and construction people who often have different priorities.

7/ Case Studies

In the course of this study, brief and incomplete reviews of three bridge projects were made. The reviews were directed to the design and construction process and did not address the quality of design from a structural engineering point of view.

One project involved a successful, technically sophisticated steel bridge in Central Region. Attention was limited to the files in the Structural Section where the Bridge Planning Report was found to be complete with the required signatures. These files did not contain correspondence related to the design and review process which may have been maintained by

the Project Manager in the Planning and Design Section. As mentioned previously, memoranda or letters of commission documenting the choice of designer were not found, although they might have been expected given the responsibility of the Section for program delivery. In view of the volume of work involved, the question of complete documentation for the project was not pursued.

A similar brief review of the files in the Southwestern Regional Structural Office for a small replacement bridge was also made. In the Bridge Planning Report, the Hydrology Report was signed by two people in the Structural Section, the Structural Design Report was signed by two people in the Structural Section and the Foundation Report was stamped by a Professional Engineer and signed by the Chief Foundation Engineer (HO). The Preliminary Design Report was signed by four people from the Planning and Design Section.

An approved and signed site plan was included. A General Arrangement Drawing was stamped and initialed by two Professional Engineers. Correspondence concerning terms of reference and fees for the design consultant was included along with a variety of correspondence with outside agencies.

Review letters to various internal offices were on file, as were the minutes of the Regional Technical Review Meeting. The files in the Regional Planning and Design Section included many of the preceding documents as well as tender documents with the special provisions, other letters to external agencies and field visit reports.

The first contract drawing was signed by the Regional Director and the Manager of Engineering and Right-of-Way. The structural drawings were stamped and initialed by two Professional Engineers as required.

A more detailed, but still incomplete, review was made of a troubled project in Central Region. Since many of the following observations are based on conversations with a few people, the information is largely hearsay and cannot be considered conclusive.

The project involved two multilane, multispan, continuous, curved, post-tensioned concrete interchange structures whose spans and heights can legitimately be considered to be at the state-of-the-art. One bridge was designed by a consultant – the other very similar structure was designed by the Structural Office.

A review of the files and conversations with Ministry personnel identified a number of problems encountered during construction. Shown in the following list are the major problems in chronological order along with the nature of corrective actions.

1. An existing 36 inch utility line was discovered during excavation for pier foundations. The line may have been installed by the local municipality after the original design. The problem was resolved by a relatively minor re-design of the piers.

2. Elevations of a pier foundation were found to be in error and a redesign and regrading were required. Apparently, the contractor did not interpret surveying data correctly.

3. After construction of a pier and during installation of a bridge bearing pad, it was found that the height of the bearings was much higher than anticipated. The bearings could not be installed between the top of the pier and the bottom of the superstructure. The solution was to raise the elevation of the entire bridge and redesign other bridge piers.

4. A number of inspection problems having to do with the falsework and support for internal hardware were noted.

5. Concrete in one portion of the bridge deck was found to be substandard. The contractor had poured concrete "at his own risk" under adverse conditions in spite of a denial of "permission to pour" by resident Ministry personnel. Subsequent in situ tests showed the concrete to be unacceptable and the concrete was removed.

6. After the bridge was completed, parts of the bearing pads were found on the ground. Investigation showed that the material in the pads was defective due to failures during the manufacturing process. The bridge had to be jacked up and the pads replaced.

A number of other problems such as concrete pouring around some of the post tensioning anchors also arose but were resolved in the field without much difficulty.

To trace the roots of these problems, the files in the Structural Section (CR) were examined and the drawings reviewed. Related files in the Structural Office (HO) and in the Planning

and Design Section (CR) were scanned to assess their completeness, but a complete check which required signatures during the technical review process was not made.

It is relevant to note that the design was completed some time before construction and stockpiled. The Bridge Planning Report was dated October, 1984. Required signatures were in place. The engineer responsible had since been promoted to another Region.

Perhaps because the project was not actually scheduled to be built, the Foundation Report was not completed before the Bridge Planning Report was filed. Apparently the practice of proceeding with detailed design without a final Foundation Report is sanctioned from time to time in order to minimize delays. The Foundation Report was signed and stamped as required. The delay in the Foundation Report did not seem to contribute to construction problems.

In the rush to begin construction, updated approvals from external agencies such as municipal public works departments were not obtained. Apparently survey data was not upgraded and transferred to contract documents. This represents a failure of communications between the Ministry and external agencies and within the Ministry. It is most unlikely that conventional engineering checking would have discovered this omission.

An apparent failure of communications occurred when current Ministry practices, with respect to surveying, were not communicated to bridge contractors. Alternatively, field staff did not ensure that correct practices were used. The practice of independent field surveying checks caught this problem before serious consequences arose.

With respect to the elevation of bridge pier tops and the size of bearing pads, a note to the effect that "bridge pad heights may be different than those shown on drawings" was made on one of the contract drawings. Also given in the drawings are the design loads for bearing design.

However, the detailed drawings of the piers show the elevations of the top of the piers to three significant decimal places – the warnings are on another drawing. Although the drawings for one bridge were prepared by an external consultant and by Ministry engineers for the other, both sets of drawings had identical formats. Neither set of drawings in the Structural Section contained professional engineers' stamps to indicate independent checking.

The reality seems to be that bearing pad dimensions were taken from published tables for pads with much lower load capacity. Increasing the pad loads had a nonlinear effect on pad dimensions. For whatever reason (which may include pressure to finish the design), the innovative nature of pad design was not recognized.

An interesting fact is that tests were performed on samples of the bridge pads by the Materials Office – the actual dimensions were known within the Ministry, but did not reach the field in time. Clearly (and very reasonably) the test engineers did not realize that the dimensions of their specimens did not correspond to the dimensions on construction drawings.

The root cause of this problem is that engineering information drawn from past experience was incorrectly extrapolated to a new domain of application. This possibility was acknowledged by the footnote on a table of pad loadings. However, the error was compounded when uncertain pier elevations were shown as precise numbers on construction drawings.

Given the uncertainty surrounding the height of the support bearings, it is reasonable to expect that the topic would have been raised during the technical review process and discussed with the Contractor during the pre-construction meeting – this represents a failure to communicate the uncertainty in bearing height.

One intriguing fact is that the drawings for the two bridges had identical formats and sequences even though they were done by quite separate groups. One possible explanation for this is that the Ministry provides standard drawings and contract package contents which are used whenever possible. In this case, standardization may well have been taken too far and encouraged major errors.

It is interesting to note that the Approvals Section in the Structural Office did recognize the increased risks due to the unusual size and height of these bridges; Senior engineers visited the site personally to inspect several critical construction procedures. The Approvals Section in Head Office seems to have been the primary conduit for construction problems and kept a good record of events. The Structural Section (CR) was involved in several (rather exciting) meetings, but, since they did not design the bridges, they do not seem to have been deeply involved.

The nature of the problems associated with replacement of a section of concrete is quite simple. Against the advice of Ministry staff, the Contractor took a calculated risk and lost. He had the right to do this and paid the price.

Given the history of problems with this project, it is possible that the Contractor was behind schedule and concerned about cost overruns and pending controversies over who would pay. Certainly his decision to pour concrete in bad weather was a rather desperate one. Inspection problems with the falsework and concreting around anchors may have had similar origins.

The need to replace the bearings after construction is also a simple type of problem – the manufacturer extended the size of his products beyond their previous range and experienced technological difficulties. Such situations are part of the learning curve and must be expected.

To provide basis for cataloging such problems, the approach of Pate-Cornell and Bea is quite useful. In their classification, the unexpected existing utility line problem and the surveying mistakes are clearly "gross errors" in the sense that everyone would have acted differently if they had been fully informed. The bearing height problem involved several gross errors in that the risks involved were not fully communicated on the drawings and to the field staff.

The concrete re-pouring problem and the replacement pad problems are "errors of judgment," since risks were inevitable and under the same conditions, rational people might legitimately make a number of decisions. Strictly speaking, these last two are not errors, but more in the nature of "bad luck."

The history of the troubled project indicates a number of errors in process (late Foundation Report, missing engineers' stamps), as well as several problems in communications (utility data, unrealistically precise drawing dimensions, inadequate recognition of risk, surveying methods).

One major recurring theme is the importance of time. The original Bridge Planning report was shelved and then put into circulation when funds became available for construction without complete reworking. When capital budgets are made available, there is great pressure to show results very quickly. Given more time, it is likely that the designers would have detailed the bearing pads rather than leave the contractor to search catalogs which did not extend into the range of the pads required.

One of the predictable effects of these problems was significant conflict between Regional structural staff, field and office construction staff, Head Office structural office staff and of course the contractor and his staff. Under such circumstances, colorful memoranda move around and discussions become rather heated. Fortunately, the temperature seems to have subsided by the time this study was underway.

Finally, to put the problem bridges in perspective, it is interesting to note the reaction of one senior engineer. When asked, he acknowledged the problems, but said "Go and look at the bridges. They are finished and they are beautiful."

8/ Summary Observations

One of the best indicators of the health of an engineering organization is the morale and confidence of its staff. In this respect, the Ministry is in excellent condition. When they learned that this study had been authorized by senior officials of the Ministry, everyone interviewed was friendly and remarkably open.

Almost without exception, the people interviewed were positive and proud of their work. The mission of the Ministry is clear and accepted. The inevitable foibles of individuals and departments are treated with bemusement rather than anger. As expected, complaints of useless bureaucracies in other offices were made, but with reasonably good humor.

In general, when measured against the criteria for "Institutional Quality Assurance" the bridge design and construction process rate very well. Ministry policies recognize and practice the principles of accountability, authorization, integrity of information. measurement, responsibility, and visibility.

One weakness is in the area of "independence" as it applies to the relationship between the Structural Section of Central Region and the Structural Office. Being responsible for program delivery, the Section is expected to serve a control function over the activities of the Structural Office. In fact, these two offices are not independent.

Similarly, through their project managers, the Planning and Design Section in Central Region is meant to exercise a control and auditing function over the bridge design process in the Region. This does not seem to be the case and communications between the Sections seem to be rather strained.

With respect to "traceability," a major weakness seems to exist in the structural filing systems in Central Region. The Structural Section does not have clear filing policies and the files for bridges in the Planning and Design Section may be incomplete.

In the case studies, a number of communication problems were identified. The Pate-Cornell and Bea criteria for categorizing errors was found to be useful.

It was also found that official requirements for the timing and approvals of reports and drawings are not always honored. In some cases, such requirements might be waived for valid reasons and it is important that such freedom be maintained. The attitude of one senior engineer is exemplary. "I try to follow all the regulations but when I can't, I don't. Then I phone my superior and tell him why I did it."

The Ministry now has so many guides and regulations that it is virtually impossible for anyone to master them even if they are not mutually contradictory. Unfortunately, some key directives were out of date at the time of this study or were under review. One prime example is Directive B-147 which is vital to bridge design and construction. As long as experienced staff are in place, the lack of formal directives is not too important, but if there is a major staff turnover, serious difficulties might be experienced.

One recurring complaint concerned the failure of others to honor their scheduling commitments, especially during the technical review process. When the organization is under public pressure to complete work, long delays caused by political uncertainties are frustrating. Both of the Regions visited have computerized schedule planning and tracking systems, but due to the many groups involved in review and the absence of standards for allowable review periods, problems continue.

9/ Suggestions

Based on a limited study such as this, formal recommendations cannot be made – especially since the organization seems to function well. However, a number of suggestions can be made that the Ministry might wish to consider.

9.1/ Consultants - Appointment and Tasks

At the present time, bridge design consultants are commissioned when necessary after the "Bridge Planning Report" has been issued. At this stage, major decisions such as pier locations, span lengths, type of construction, bridge depth and bridge width have been made. While his task may be complicated and involve sophisticated computer analysis, for example, the consultant's role is essentially to detail the bridge – not really to design it.

To do his task, the consultant is given a comprehensive design code with many standards for materials and components along with standard drawings and Ministry computer software for analysis. The contract box must be of a specific form. After he is finished, the Ministry then performs a detailed technical review of what he has done. In reality, the consultants are almost told what to do.

Consultants are paid to take responsibility, but, in the current Ministry setup, very little discretion or originality is required. Much of the interesting design work is completed for the Bridge Planning Report.

By breaking the design process into two parts, information must be transferred between organizations even if detailed design is done by Head Office. In reality, the set of activities, starting with preliminary work for the Bridge Planning Report right through to the final contract documents, is one continuous process as evidenced in building design.

These thoughts suggest that the Ministry might consider relocating the decision as to who will design a bridge so as to assign the whole design process to one organization. A consultant capable of detailed design should be capable of preparing the Bridge Planning Report as well. Such an increase in responsibility should be welcomed by good organizations, since it provides more scope for creativity and simplifies communications. The distribution of work between the regions, Head Office and external consultants need not change significantly although the detailed assignments would be different.

The Ministry might also consider reducing the constraints under which the consultants work. They are paid to take responsibility and should be required to take it.

One possibility that should be resisted is the trend to turn the Regional Structural Sections into managers of consultants. Experience has shown that to effectively control technical work,

the comptrollers must also be involved in the work. Maintenance of solid technical competence throughout the Ministry is of vital importance to quality assurance.

9.2/ Central Region and the Fundamental Directive

Based on observations in this study, the Structural Section in Central Region does not seem to assume full responsibility for program delivery. This is partly due to the complex nature of bridge structures in Central Region. The physical location in the same building as the Head Office structural group is also a factor.

There seems to be two alternative courses of action. Firstly, the Structural Section can be relocated, reorganized, and made to function independently of the Structural Office. Alternatively, the fundamental directive can be adjusted to reflect the reality of Central Region. The Structural Section could be incorporated into the Structural Office rather than into Central Region. The latter approach would be very similar to present conditions and provide a clear administration for program delivery.

9.3/ Simplifying the Process

It is generally true that very little time involved in developing a highway is taken up by bridge design. Major delays are caused by property acquisition and the political process. Once the decision has been made to build a bridge however, it is often essential that construction begin as soon as possible.

Based on conversations during this study and a review of the functions performed in each stage of contract preparation, the major source of potential time savings is in the technical review process. A great deal of this work consists of one group checking to make sure that another group is doing their job correctly.

A recurring complaint concerned the final stages of review. By this time, contract documents have been through a number of detailed checks including controls by the project managers. In this regard, it is well know from the nuclear industry that, if a process has too many checks, people early in the process tend to become careless and leave it to the next level. The question "If the Regions are responsible for program delivery, why not let them do it?" seems a valid one.

In general, the Ministry has a very enlightened attitude to the professionalism of it staff. Engineers are expected to use their judgment and to take responsibility. The concept of "job

enrichment" as a powerful motivator is widely recognized in modern management theory. It is also widely believed among those who have pondered the question of "human error" that the best approach is to develop a well educated, competent core of people and then count on their self-discipline and pride to ensure quality. It may be that a general liberalization of the design process with more responsibility given to individuals or groups could significantly increase productivity while maintaining quality.

The removal of some Head Office checking functions would be consistent with the fundamental directive and significantly simplify communications. It would also remove a source of some irritation.

9.4/ Scheduling

Given the level of frustration associated with delays in the technical review process, the Ministry might consider establishing a set of norms for acceptable time periods for the various offices involved. Comments received after the allocated period could be ignored at the Technical Review Meeting.

9.5/ Budget Smoothing

Significant variations in capital budgets have major effects on quality assurance in the design and construction process. In lean years, minimum staff levels must be maintained and projects are designed and stockpiled. As mentioned previously, when these designs are activated during periods of intense activity, a number of serious problems can arise leading to serious problems.

When budgets are increased suddenly, the Ministry finds itself understaffed. Given the lead time required to train staff, more work tends to go to consultants. Consultants expand their activities and begin hiring in competition with the Ministry for experienced personnel. Since private industry has great flexibility in salaries and other benefits, good Ministry personnel are tempted to leave.

No solution to this very old problem is known, but the problems associated with large budget variations should be considered in strategic planning.

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Appendix A

MTO Individuals Interviewed

R. Alexander, Head, Document Review Section, Central Region.

R. R. Barsalou, Area Engineer - Structures, Structural Section, Central Region.

V. F. Boehnke, Head, Structural Section, Central Region.

G. C. E. Burkhardt, Head (Retired), Structural Section, Central Region.

Dr. R. A. Dorton, Manager, Structural Office, Head Office.

B. Ferago, Design Engineer, Design Section, Structural Office, Head Office.

D. Grey, Supervisor, Engineering Support Unit, Planning and Design Section, Central Region,

R. Hanton, Manager, Engineering and Right of Way, Central Region.

A. Ho, Head, Structural Section, Southwestern Region.

M. Holowka, Head, Approvals Section, Structural Office, Head Office.

R. Jeffries, Structural Technician, Structural Section, Central Region.

B. Kennedy, Project Manager, Planning and Design Section, Central Region.

.A. McConnell, Manager, Engineering and Right of Way Office, Southwestern Region.

R. P. Northwood, Manager, Engineering Materials Office, Head Office.

R. W. Oddson, Senior Manager, Survey and Design Office, Head Office.

K. Pilgrim, Area Engineer - Structures, Structural Section, Central Region.

W. Roy, Senior Project Manager - Freeway Design, Planning and Design Section, Central Region.

B. R. Steeves, Scheduling Officer, Central Region (by letter).

T. Tam, Approvals Section, Structural Office, Head Office.

D. A. Waller, Manager, Construction Office, Southwest Region.

T. Zander, Area Construction Engineer, Construction Office, Central Region.

Appendix B

Communications Theory - Selected Concepts

Modern work in the fields of industrial psychology and sociology has established many of the characteristics and basic criteria for effective communications. For example, well documented human factors that contribute to faulty communication and decision making include: "the misuse of heuristics; selective perception; poor intuitive statistical capabilities; a sensitivity to data presentation; a priori commitment; limited individual capacity and biases in processing feedback." System factors include information overload, distraction and noise, including the effects of environmental stresses.

Two basic classes of communication problems of particular relevance to this study can be identified:

Communication Within Organizations

An understanding of communication principles, information flows, and interpersonal relationships is essential if the operations of an organization are to be understood. Difficulties in human communication, together with inherent human characteristics, have particular consequences and manifestations in any organizational structure. An extensive overview of the literature is given by Joblin et al (1987).

Some well documented observations include: (a) communication networks increase in effectiveness as the relationships among individuals become more stable (Down, 1967); (b) vertical communication tends to be slow; (c) horizontal and diagonal communications are hindered by self interest or inter-branch conflict (Lee and Zwerman, 1980); and (d) the vast majority of all communication in large organizations is informal (Down, 1967).

Besides the distortion of information by inherent limitations in the "sender-medium-receiver" chain, information within organizations is also distorted by the self-interest of individuals. In particular, unfavorable information is often forgotten (Bella, 1987).

In addition, individuals who originate disturbing information may be isolated or reorganized out of existence. As a result, information passed upwards in a hierarchy tends to be distorted so as to more closely reflect what senior officials would like to hear. Thus information is exaggerated if it favors a senior individual and minimized if it does not (Ferguson and Ferguson, 1980). Since information affects prestige and power (Brown, 1980), one must expect

conscious distortions and filtering of information. Only a firmly embedded common objective can minimize intentional distortion.

Most officials systematically employ counterbiasing to compensate for distortions and attempt to reduce their reliance on information through the use of redundant sources. However, information overload can result, leading to a reduced rate of message handling. An organization may react by filtering information or adding assistants, but these may lead to greater distortion and more omissions.

Communication Among Organizations

A project is affected not only by communication within organizations, but also by communication between the clients, designers, project managers, contractors and a variety of ancillary organizations, such as material suppliers. Some bias resulting from group decision making have been investigated (Janis, 1982, Gouran and Hirokawa, 1986)

Patterns of communication have changed in recent years as the economic, technological, social and legal environment of civil engineering has evolved (Moorhouse, 1987). Classical, straightforward communication between clients, contractors and engineers has changed to include, for example, increased governmental control, risk management programs, increased participation in decision processes by other parties, and peer reviews at several stages.

If failure occurs, third parties and the legal system soon become part of the organizational structure. One can consider the real players as members of support organizations with several communication links immersed in a complex environment. In this case, filtering and distortion of information results from a combination of responsibilities, overlapping hierarchies of formal authorities, self-serving interests, institutional pride and commitment, and other inherent limitations. This setting is characteristic of the construction industry and, to the writers' knowledge, there has been no in-depth study of this situation.